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PATENT APPLICATION

LOW TEMPERATURE WAFER-LEVEL MICRO-ENCAPSULATION

CLAIM OF PRIORITY

This application claims priority from U.S. Provisional Patent Application No. 60/450,637 entitled "MEMBRANE SWITCH COMPONENTS AND DESIGNS" by David Forehand, filed on February 24, 2003 (Attorney Docket No. 2657000) and is hereby incorporated by reference.

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates generally to the packaging of electromechanical or micromachined devices and, more particularly, to individual encapsulation of microelectromechanical system (MEMS) and micromachined devices, such as sensors, actuators, and/or switches.

Description of the Related Art

MEMS and micromachined devices are presently utilized for a variety of sensor, imaging, and actuation applications. These include acceleration and pressure sensors for automotive and biomedical applications, infrared sensor arrays and arrays of micromirrors for imaging and displays, and RF switches for controlling and routing wireless signals. The unique characteristics of these devices, including their superior ruggedness, reduced size, and low potential cost, can allow

them to become an enabling technology for a variety of military and commercial applications. However, the present challenge in the development of this technology is the effective, low-cost packaging of these devices. The requirement for a hermetic package that makes no contact with the MEMS circuitry creates many packaging difficulties. In addition, the need for a controlled atmosphere or vacuum within the package is an extra constraint not normally encountered in packaging of more conventional electronic devices. As such, several methods have been investigated to resolve these packaging problems.

Currently, there are two general approaches that can be employed to protect MEMS circuitry. The first method involves encasing the MEMS circuitry in traditional, hermetic ceramic or metal packages with a lid. However, this approach has several disadvantages, such as being bulky, expensive, and requiring much back-end processing and assembly (which leads to a yield loss). For example, in Radio Frequency (RF) applications, a ceramic package may not be desirable due to its high RF losses, which significantly reduce the low-loss advantages of RF MEMS, and due to its difficulties in tuning the RF ceramic package to the desired frequency, which worsens as the frequency increases.

A second method, wafer-level packaging, has recently been utilized to incorporate the advantages of batch processing to

the packaging process. This enables the packaging to be accomplished at the wafer-level, within the environs of a cleanroom. This substantially reduces cost and improves the yield of packaged MEMS circuitry. Fundamentally, these process forms of packaging require a separate lid wafer to be processed. The processed lid wafer has a number of etched cavities that will be utilized to cover the MEMS. The etched lid wafer is then adhered to a wafer containing a multitude of MEMS devices. However, a large seal ring around each MEMS circuit is required to implement the bonding of the two wafers. Moreover, to make electrical connections with the MEMS circuitry requires a through-wafer via channel or RF feed-through underneath the seal ring. Depending on circuit requirements, this connection may be both difficult and/or expensive to manufacture. Wafer-level packaging therefore has its own set of disadvantages, more particularly, requiring significant seal ring area, precise double-wafer alignment and bonding, while incorporating difficulties in electrical interconnections, susceptibility to wafer surface roughness, and possibly utilizing high-temperature processing.

More recently, techniques have been established to fabricate and encapsulate a protective housing around the MEMS devices. However, these techniques utilize vacuum encapsulation, high temperature processing, and molten metal sealing for hermeticity. While there are classes of devices

which operate in the near-vacuum conditions, can tolerate high processing temperatures (> 600C), and are not impacted by the close proximity of metallized seal surfaces, these are a limited subset of overall MEMS devices.

Therefore, there is a need for a MEMS packaging technique that is both economical and easy to implement for a large variety of MEMS and micromachined devices to allow for widespread use and manufacture of MEMS and micromachined devices.

SUMMARY OF THE INVENTION

The present invention provides for packaging at least one microscopic device. A housing with at least one aperture is formed over the at least one microscopic device. A protective material is deposited, wherein the protective material is at least configured to have a viscosity such that the protective material does not flow into movable regions of at least one microscopic device. The protective material is cured.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of the present invention and the advantages thereof, reference is now made to the following descriptions taken in conjunction with the accompanying drawings, in which:

FIGURE 1 is a flow chart depicting the process for the creation of a micro-encapsulated package to protect the MEMS or micromachined device;

FIGURE 2 is a block diagram depicting a sacrificial layer deposited on a MEMS device;

FIGURE 3 is a block diagram depicting a structural layer deposited on a sacrificial layer and a MEMS device;

FIGURE 4 is a block diagram depicting protective cage on a MEMS device with the sacrificial layer removed; and

FIGURE 5 is a block diagram depicting protective layer deposited on the protective cage.

DETAILED DESCRIPTION

In the following discussion, numerous specific details are set forth to provide a thorough understanding of the present invention. In particular, the details are specific to packaging for MEMS and micromachined devices, or other similarly electromechanical devices. Many of these applications require insulating materials to form the microcavity and package. However, those skilled in the art will appreciate that the present invention can be practiced, with other materials, without such specific details. In other instances, well-known elements have been illustrated in schematic or block diagram form in order not to obscure the present invention in unnecessary detail.

Referring to FIGURE 1 of the drawings, the reference numeral 100 generally designates a flow chart depicting the process for the creation of a micro-encapsulated package to protect the MEMS or micromachined device.

During the process of encapsulating a MEMS or a micromachined device, certain underlying conditions for the process as a whole are typically preset. Conditions, such as the atmospheric composition of the processing environment, can have a substantial impact on process and can affect the resulting product. For the process of the creation of a micro-encapsulated package to protect the MEMS or micromachined device, typically an inert gas atmosphere with a pressure above 1 Pascal is utilized. Also, during the entire process the temperature of the atmosphere or the devices should typically not rise above 600° C or above a temperature sufficient to melt or damage a MEMS or micromachined device.

Additionally, the process for the creation of a micro-encapsulated package to protect the MEMS or micromachined device 100 is more applicable to a wider variety of MEMS and micromachined devices compared to conventional techniques and processes. The process 100 utilizes conventional semiconductor and micromachining manufacturing devices to form and remove material layers. Also, the process 100 is amenable to both vacuum and controlled atmosphere packaging and utilizes significantly lower temperature than the melting

point of aluminum. Also, the process 100 incorporates insulating materials for the hermetic encapsulation. This gives the process 100 a much wider range of applicability, for example certain RF MEMS.

In step 101, a sacrificial layer is placed over the MEMS device or devices to form a temporary encapsulation. The sacrificial layer can be composed of a variety of materials. For example, an organic material such as a photoresist or polyimide can be used. However, the sacrificial layer should possess the property of easy removal by heat, wet chemical etching, or plasma etching. Moreover, the thickness of the sacrificial layer can also vary. The sacrificial layer should be thick enough such that during operation, the movable membrane does not contact the housing and be thick enough to prevent contact between the movable region and the subsequent liquid protective material application, typically between 0.2-10 microns thick. FIGURE 2 illustrates a sacrificial layer 201 covering a MEMS device and substrate 220.

In step 102, a structural material is deposited on top of the sacrificial layer. For many applications, such as with RF MEMS, the structural layer should be an insulator. For example, Silicon Dioxide (SiO_2) or Silicon Nitride (Si_3N_4) can be used. However, a conductor can be used as a structural layer. The choice of the structural layer will depend on desired electrical properties of the packaging. A variety of

materials, though, including metals, can be used. Moreover, the thickness of the non-sacrificial, structural layer can vary, but should have sufficient structural integrity so as to support the subsequent application of a liquid encapsulating material. The structural layer, though, may be between 0.2-20 microns thick and should have tensile to slightly compressive stress. Furthermore, there are a variety of manners to deposit the structural layer. However, the method employed should operate at a low temperature that will not adversely impact the MEMS or the sacrificial layer or sacrificial layers. Also, FIGURE 3 depicts a structural layer 310 deposited on top of a sacrificial layer 320 and a MEMS device and substrate 330.

In step 103, open regions within the cage structure are formed by removing material from the structural layer. There are a variety of means to remove portions of the structural layer that can include, but not limited to, sputtering, plasma etching, and wet etching. The size of the apertures of the cage can also vary. However, the size and spacing of the apertures should be large enough and/or spaced close enough such that the sacrificial layer can be later removed, but the apertures should be small enough as to not allow the protective material, such as Spin-On Glass (SOG), to encroach into the cavity and contact the movable structure. In addition, there should remain sufficient material to be

structurally strong enough to not collapse upon application of the protective, encapsulating material.

In step 104, the sacrificial layer is removed to create a microcavity in the space between the cage and the MEMS or micromachined device. There are a variety of manners to remove the sacrificial layer. For example, sublimation, sputter etching, ion beam milling, plasma ashing or use of wet chemicals can be employed. Also, FIGURE 4 depicts a cage 410 deposited on top of a MEMS device 420.

In step 105, the appropriate protective material is applied to encapsulate the MEMS device. The appropriate material is selected by virtue of the properties of the material, more particularly, viscosity, surface tension, and hermeticity after curing or fixing. FIGURE 5 depicts protective material 520 deposited on a cage 510 on top of a MEMS device and substrate 500.

There are certain liquids that possess inappropriate properties. According to steps 106 and 110, if the protective material does not wet the cage, then the surface tension is too high, and the material is not appropriate. According to steps 107 and 110, if the protective material wicks into the microcavity and contacts any movable portions of the device to be protected, for example a MEMS device, then the surface tension is too low, and the material is not appropriate.

However, there can be liquids that possess appropriate

properties to protect the MEMS or micromachined devices. According to steps 108 and 111, if the protective material sits on top of the cage, which may also fill or partially fill the gaps and open regions of the cage, 530 and 540 of FIGURE 5, then the material is appropriate because the surface tension is within the desired range. According to steps 109 and 111, if the protective material wicks into the cage but does not wick onto the movable regions of the device to be protected 550 of FIG. 5, for example a MEMS device, then the material is appropriate because to the surface tension is within the desired range.

According to step 112, after the appropriate material has been applied, the appropriate material is cured or fixed to seal the device to be packaged. The cured or fixed material should provide a hermetic barrier to prevent the ingress or egress of gasses or particles into the protective cavity. A unique feature of this technique is that the final sealing process can be configured to incorporate either an inert atmosphere or a vacuum atmosphere within the package microcavity. Depending on the type of device, one of these two environments may be more desirable. For example, infrared bolometers and micromechanical resonators typically require a vacuum atmosphere to operate properly. Conversely, optical micromirror arrays and RF MEMS switches only require a dry, inert gas environment. There are a variety of materials that

can be used as a protective material that include, but not limited to, spin-on-glass (SOG). Another unique feature of this process is that the application of the protective material and encapsulation of the microcavity can be accomplished at relatively low temperatures, for example below 600° C. The temperature should be necessary to cure or fix the protective material. The protective material should also possess the properties of structural strength, non-conductivity of electricity, hermeticity, and low processing temperatures. However, depending on the desired use, the structural integrity of the material, its process temperatures, and its ability to conduct electricity can vary.

In step 113, additional material may be deposited onto the wafer. Typically, the additional material is to increase the hermeticity of the packaged microcavity. However, step 113 may be necessary depending on the desired application. The additional material can be the same or similar material to structural layer and depends on desired electrical properties. For example, for an RF MEMS application, the additional material can be Silicon Dioxide (SiO_2) or Silicon Nitride (Si_3N_4).

It will further be understood from the foregoing description that various modifications and changes can be made in the preferred embodiment of the present invention without departing from its true spirit. This description is intended

for purposes of illustration only and should not be construed in a limiting sense. The scope of this invention should be limited only by the language of the following claims.